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The Interface Effect in the Water Absorption in Ceramic Brick

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Abstract

The analysis of moisture migration in building materials and elements is crucial for its behaviour knowledge also affecting its durability, waterproofing, degradation and thermal performance. Based on this breach it is intended to analyse the interface effect in the capillary process in ceramic brick. Ceramic brick is a common material in Portuguese exterior walls, where usually it has mortar joints. In the foremost cases, Portuguese exterior walls are multilayer walls with materials in perfect contact and/or with an air space. Knowing that, in this paper, an experimental research using samples to capillary tests are used considering four different cases: monolithic and three interfaces: perfect contact, air space and hydraulic continuity (mortar).

Since a long time, moisture is one of the primary causes for the observed damage on the buildings envelope, increasing the importance of this research with the goal of controlling the real moisture migration process. This paper has two special purposes: (a) The analysis of ceramic brick capillarity coefficient without interfaces (monolithic) and with three different interfaces: perfect contact, air space and hydraulic continuity (mortar) and (b) The calculation of the hydric resistance in the interface that conditions the maximum flow transmitted FLUMAX. This value is an important input in numerical simulations with multilayer building components and is a parameter to be obtained experimentally.

In the first weights the water front is lower than the interface position so it would be expected that the capillary coefficient, calculated for the first step, is not to much influenced by the interface. It is expected that the maximum flow transmitted – FLUMAX, in the three different interfaces, is lower to air space, higher to hydraulic continuity, being the perfect contact in the middle

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1. Introduction

Building envelope systems can see their components exposed to contact with liquid water, for example cladding wetted by rain or sheathing or structure wetted by water infiltration. The role of water in the mechanism of deterioration of porous building materials has been recognized for a long time. The durability of building structures is thus critically determined by the rate at which water infiltrates and moves through a porous structure. Because of its economic implications, the problem of water movement in porous building materials has received great attention of physicists and engineers.

Portuguese exterior walls are usually multilayer walls with joints which justify the moisture transfer knowledge about the continuity between layers. In literature, several studies concerning the liquid transport in multilayered composites can be found, however, only a limited number of values for the interface resistance in multilayered composites are found. Several years ago, Freitas [1, 2] considered three different interfaces configurations:

- Hydraulic continuity – when there is interpenetration of both layers porous structure (for example: mortar joints),
- Perfect contact – when there is contact without interpenetration of both layers porous structure,
- Air space between layers – when there is an air box of a few millimetres wide.

This paper intends to report the experimental work carried out with brick specimens, aiming to evaluate the effect of different interface configurations in the water capillary absorption of brick specimens. The interfaces in study are the perfect contact, hydraulic contact and air space between layers. Hydraulic contact corresponds to a contact configuration where there is an interpenetration of the porous structure of both layers. Perfect contact corresponds to the case where the layers are overlapping, maintaining physical contact, however without interpenetration of their porous structures. The air space can be seen when there is a gap of a few millimeters between layers. The experiments carried out with the specimens with different interfaces aimed to calculate the maximum moisture flow through the interface.

2. Materials and methods

The experiments conducted in this study are guided by the outline of the partial immersion method as explained in the European Standard "Thermal performance of buildings and building components - Determination of water absorption coefficient" [3, 4]. Three specimens of each configuration were tested and the four types of specimens tested are represented in the Figure 1. Prismatic samples of clay brick with a dimension of 50x50x100 mm^3 were tested (3 samples by each configuration). All the specimens were sealed in the lateral faces with an epoxy coating to avoid the evaporation through these sides and assure the unidirectional moisture flow from the bottom to the specimens' top surface.

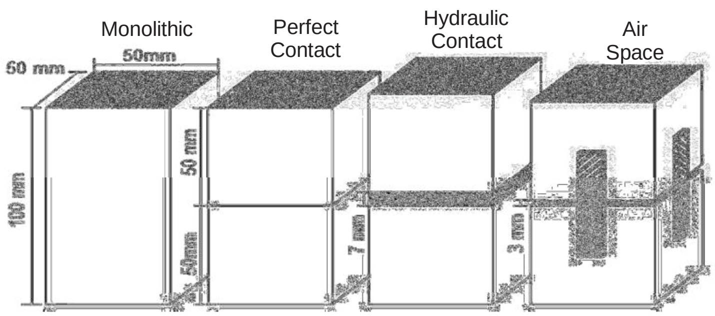

Fig. 1. 3D virtual representation of the different types of specimen tested.

Capillary absorption data were obtained by placing the samples in distilled water. Their base was submerged only a few millimeters (~1-3) in order to avoid build-up of hydrostatic pressure. The environmental laboratory conditions were 22°C and 60% RH during the duration of the experiments. Experiments were conducted at 22ºC and for immersion periods, from several minutes to about 22 days. The samples were placed in constant-temperature water bath controlled within ±0.5 ºC to avoid changes in liquid viscosity that might affect the absorption rate [5]. After soaking, the moisture content of samples was calculated based on the increase in the sample weight at corresponding times. For this purpose, at regular time intervals, ranging from 30 min at the beginning to 12 hours during the last stages of the process, the samples were rapidly removed from the water bath and superficially dried on a large filter paper to eliminate the surface liquid. The samples were then weighed to determine the moisture uptake. The samples were subsequently returned into analysed solution via wire mesh baskets and the process was repeated, consequently.

A schematic plot of the increase in weight of the test specimen versus the square root of the time indicates that the specimen weight increases linearly before it comes close to the saturation limit. The slope of this linear variation is called the capillary absorption coefficient, A, and can be mathematically written as:

$$\frac{m - m_0}{S} = A\sqrt{t} \tag{1}$$

where m is the sample mass at time t, m_0 is the initial sample mass, S is the liquid contact surface area and t is the time.

This experimental campaign analysed in detail three different interfaces configurations and the capillarity process of samples with and without joints. Prior to testing the specimens were previously dried in an oven, at a temperature of 65°C to stabilize the mass content and subsequently placed in a climatic chamber with 22±0.5ºC of temperature and 50±1% of relative humidity, until reached the equilibrium state. The imbibition process occurred in laboratory at isothermal conditions. All surfaces of each test specimen are sealed except the top surface open to the ambient air and the bottom surface in contact with liquid solution, as previously described.

In the perfect contact situation it can be consider that there is continuity in the temperature between the two layers and equivalence of the thermal flow, but about relative humidity the experimental studies developed by Freitas [1, 2] show a hydric resistance in the interface that conditions the maximum flow transmitted – FLUMAX. In the air space between the layers, the equivalence of the relative humidity allows one to establish a relationship between the values for relative humidity of the materials on the either side of the interface established by a function. In the hydraulic continuity the equivalence of the capillary pressure causes a relationship between the values of moisture content of the two materials in the interface established by a function R(Pc).

3. Results and Discussion

3.1. Capillary Absorption Coefficient

Typical plots of mass gain versus the square-root of time, at 22°C, are shown in Figures 2 to 5, as the calculated capillary absorption coefficient.

The moisture absorption process used in the experimental campaign is based on an adaptation of EN 1015-18 [7]. During the absorption tests the water temperature was kept constant at 22±0.5 ºC. The reproducibility of the experiments was tested by independently repeating the measurement of water absorption coefficient, under identical operating conditions, and in the vast majority of cases, repeated measurements of water absorption coefficient did not differ by more than 10%.

Figure 2 show the results of the average mass variation per contact area in the capillary absorption process for three samples of monolithic red clay brick. The water absorbed curve, by capillary action, as an absorption first step (short-time faster) is directly proportional to the square root of time just as it would be expected [8].

This result is quite the same for the monolithic samples and also for the samples with different kind of interfaces (see Figures 3 to 5). In fact in the first weights the water front in lower than the interface position so it would be expected that the capillary coefficient, calculated for the first step, should not be influenced by the interface. The absorption coefficient, for all studied cases is around 0.07 ($kg/m^2s^{0.5}$), an expected result [9].

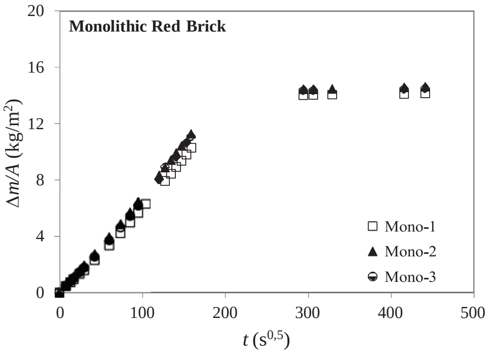

Fig. 2. Capillary absorption curve of monolithic specimens partially immersed in water, as a function of the root of time.

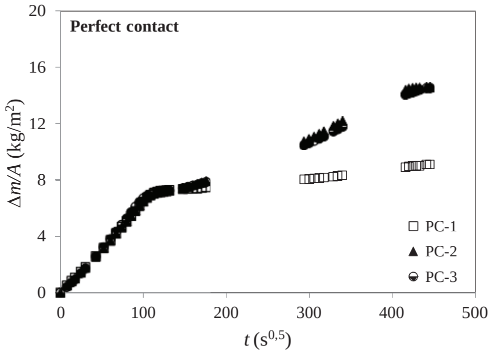

Fig. 3. Capillary absorption coefficients obtained for clay brick specimens partially immersed in water, with perfect contact interface.

The experimental tests to analyse the perfect contact interface were carried out with samples with the same material layers (clay brick). These contact layers were carefully done to guarantee the perfect contact between the surfaces. In Figure 3, it is possible to observe that when the moisture reaches the interface (at the end of 4h to 5h) there is a slowing of the wetting process due to the interfaces hygric resistance. This behaviour clearly shows the existence of a resistance that is associated with the maximum flow transmitted – FLUMAX, defined by the common pendent of the mass variation in function of time.

Whenever the layers of consolidated materials are separated by an air space, there is an hidric cut that prevents the moisture transfer in liquid phase so the water transport starts to be in steam phase. For this purpose, test samples were carried out with two same material layers (clay brick) separated by about 3 mm of an air space. The slowing of the wetting process due to the interfaces hygric resistance was observed, once again, at the end of 4h to 5h (see Figure 4). However, this hygric resistance is higher than in the perfect contact interface test so it can be shown the extremely slow weight gain. This behaviour clearly shows again the existence of a resistance that is associated with the maximum flow transmitted – FLUMAX, defined by the common pendent of the mass variation in function of time that, in this case, is lower.

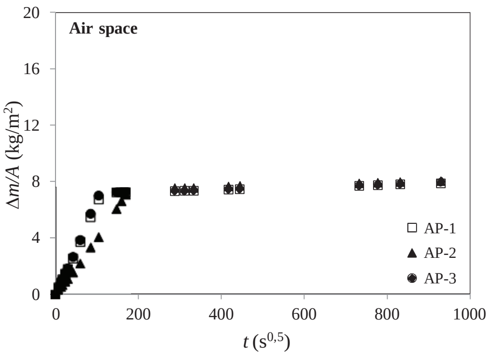

Fig. 4. Capillary absorption coefficients obtained for clay brick specimens partially immersed in water, with air space interface.

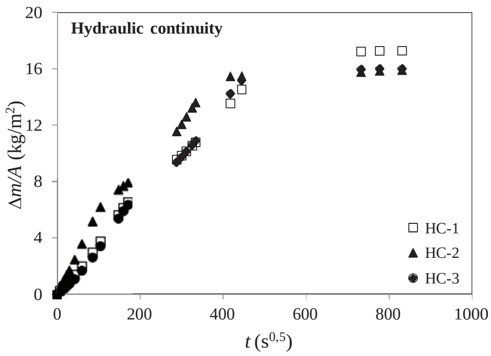

Fig. 5. Capillary absorption coefficients obtained for clay brick specimens partially immersed in water, with hidraulic continuity.

The hydraulic continuity interface configuration is typical when the layers are built in field where there is an interpenetration of both layers porous structure. In this case, test samples were carried out with two same material layers (clay brick) with a mortar joint of 3 mm. One more time, in Figure 5, it is possible to observe that when the moisture reaches the interface (at the end of 4h to 5h) there is a slowing of the wetting process due to the interfaces hygric resistance. This resistance is the lowest as it was expected considering the interpenetration of both materials.

This behaviour allows us to consider the existence of a resistance associated with the maximum flow transmitted – FLUMAX.

3.2. Maximum Moisture Flow

The calculation of the hydric resistance in the interface that conditioned the maximum flow transmitted – FLUMAX is very important. This value is an important input in numerical simulations with multilayer building components and it is a parameter experimentally easy to obtain. Based on the results of the vertical water absorption tests the maximum flows transmitted were determined by the slope of the mass variation per contact area in function of the time [1, 2]. The calculations admit that the first layer is saturated and that all the increased weight becomes from the relative humidity that penetrates the interface. In Figure 6 it is possible to identify, for the three different interfaces, the resistance associated with the maximum flow transmitted which corresponds to the weight increased curves slope in the discontinuity region.

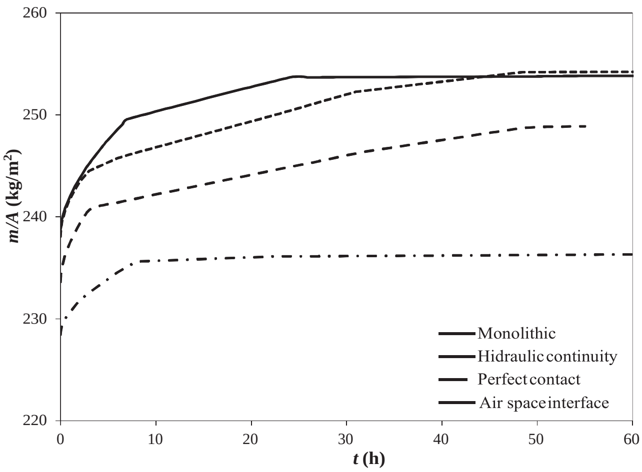

Fig. 6. FLUMAX interfaces effect: a) Monolithic, b) Hydraulic continuity interface, c) Perfect contact interface and d) Air space interface.

Table 1. Maximum flow transmitted in the three different studied interfaces.

Interface Configuration	**FLUMAX (kg/m^2s)**
Hydraulic Continuity	~70 $x10^{-6}$
Perfect Contact	~50 $x10^{-6}$
Air Space	~4 $x10^{-6}$

Table 1 shows, for the three different analysed interfaces, that the maximum flow transmitted (FLUMAX) are in agreement with the results presented by Freitas [1, 2]. In this work the author presented a study with air space and perfect contact interfaces, and the results obtained were $4x10^{-6}$ kg/m^2s and $44x10^{-6}$ kg/m^2s respectively.

The maximum moisture flow values determined for the hydraulic contact specimens showed some dispersion in the experimental results, compared with the other experiments. However it is important to be in mind that this kind of interface's hydric performance is very dependent of various mortar layer's execution factors, like the type of cement used, the water/cement ratio, heterogeneities imposed by the fact that it is handmade, even mortar's curing conditions, among others. As an example of the mortar's curing conditions influence, Derluyn et al. [10] performed tests with three types brick specimens containing a mid-layer of mortar executed with three different curing conditions (mould cured, dry cured and we cured specimens). The results showed an important decrease of the cumulative moisture flow for dry cured mortar and to a less extent for wet cured mortar compared to the values obtained for the moulded mortar, confirming the influence of the curing conditions on the hygric properties of mortar joints, by modification of transfer properties and interface resistances.

4. Conclusions

The results of the experimental campaign of absorption in samples of clay brick with and without joints and joints with different contact configurations (perfect contact, hydraulic continuity and air space between layers) showed that when the moisture reaches the interface there is a slowing of the wetting process due to the interfaces hygric resistance [1, 2, 11, 12]. The main conclusions were:

- The water absorbed curve, by capillary action, as an absorption first step is directly proportional to the square root of time, as expected [3, 4];
- The calculation of clay brick capillarity coefficient without interfaces (monolithic) and with three different interfaces: perfect contact, air space and hydraulic continuity (mortar) leads to a similar value, in the first weights the water front in lower than the interface position so as it would be expected the capillary coefficient, calculated for the first step, was not influenced by the interface;
- The absorption coefficient, for all studied cases is around 0.07 kg/m2s0.5 as expected [9];
- The calculation of the hydric resistance, in the three different interfaces, that conditioned the maximum flow transmitted – FLUMAX was between $4x10^{-6}$ kg/m^{2}s and $70x10^{-6}$ kg/m^{2}s, lower to air space and higher to hydraulic continuity;
- The maximum flow transmitted – FLUMAX is an important input in numerical simulations with multilayer building components and is a parameter always obtained experimentally.
- This result obtained for the three different interfaces analysed will be an important parameter for example in the design and optimization of the wall base ventilation system considering real multilayer walls [13].

Acknowledgments

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References

[1] Freitas V.P. de, Moisture transfer in building walls – Interface phenomenon analysis. PhD Thesis, FEUP, Porto, Portugal; 1992. (in Portuguese)
[2] Freitas V. P. de, Abrantes V. and Crausse P. - Moisture migration in building walls - Analysis of the Interface Phenomena - Building and Environment, the International Journal of Building Science and its Applications, vol. 3 1, no. 2, 1996, ISSN0360- 1 323, Great Britain.
[3] CEN: Thermal Performance of Buildings and Building Components, Determination of Water Absorption Coefficient, TC 89/WG10 N70, 1994.
[4] Rego T. Efeito de soluções aquosas salinas nos processos de embebição de paredes com múltiplas camadas. Dissertação de Mestrado, Faculdade de Engenharia da Universidade do Porto, 2014.
[5] P. Mukhopadhyaya, P. Goudreau, K. Kumaran and N. Normandin: Effect of Surface Temperature on Water Absorption Coefficient of Building Materials, Institute for Research in Construction, Report NRCC-45369, National Research Council, Ottawa, Canada, 2002.
[6] Pel L., Moisture Transport in Porous Building Materials. PhD Thesis, Eindhoven University of Technology, 1995.
[7] EN 1015-18 - Methods of test for mortar for masonry – Part 18: Determination of water absorption coefficient due to capillary action of hardened mortar. CEN, 2002.
[8] Bomberg M., Moisture flow through porous building materials, Repport nº 52, Division of Building Technology, Lund Institut of Technology, Lund-Sweden, 1974.
[9] Freitas V.P. de, Torres I., Guimarães A. S.: Rising Damp – Technical Note. FEUP, October, 2008.
[10] Derluyn H, Janssen H., Carmeliet J.. Influence of the nature of interfaces on the capillary transport in layered materials. Construction and Building Materials, 2011, 25, 3685–3693.
[11] Qiu X. Moisture transport across interfaces between building materials. PhD, Concordia University, Montreal, 2003.
[12] Wilson, M. A., Hoff, W. D., Hall, C., Water Movement in Porous Building Materials-XIII. Absorption into a Two-Layer Composite, Building and Environment, 1995, Vol. 30, No 2, pp. 209-219.
[13] Guimarães A. S., Delgado J. M. P. Q., Freitas V. P. de, Mathematical Analysis of the Evaporative Process of a New Technological Treatment of Rising Damp in Historic Buildings, Building and Environment, 2010, Vol. 45 (11), 2414-2420.